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REPORT SUMMARIZES RESEARCH RESULTS ON SUBJECT GRANTS

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1. INTRODUCTION

This final report covers the period from October 1, 1974 to September 30, 1976 on Grant DAHC04-74-G-0177 and from October 1, 1976 to May 31, 1978 on Grant DAAG29-77-G-0010 and contains a summary of the work performed under these grants titled "Phenomena of Second Fracture in Structural Dynamics". Section 2 summarizes the technical results achieved under the grant, Section 3 lists the research personnel and a listing of publications is given in Section 4.

2. TECHNICAL RESULTS

Even though the title of the subject grants was "Phenomena of Second Fracture in Structural Dynamics", it was soon realized after the start of the project that a much more systematic and comprehensive study of single fracture of beams in bending needs to be undertaken before a study of phenomena of second fracture could be attempted.

The dynamic fracture response of a long beam of brittle elastic material subjected to pure bending was studied first. If the magnitude of the applied bending moment is increased to a critical value, a crack will propagate from the tensile side of the beam across a cross section. An analysis is presented by means of which the crack length and bending moment at the fracturing section are determined as functions of time after fracture initiation. The main assumption on which the analysis rests is that, due to multiple reflections of stress waves across the thickness of the beam, the stress distribution on the prospective fracture plane ahead of the crack may be adequately approximated by the static distribution appropriate for the instantaneous crack length and net section bending moment. The results of numerical calculations were shown in graphs of crack length, crack tip speed, and fracturing section bending moment versus time. It was found that the crack tip accelerates very quickly to a speed near the characteristic terminal speed for the material, travels at this speed through most of the beam thickness, and then rapidly decelerates in the final stage of the process. The results also apply for plane strain fracture of a plate in pure bending provided that the value of the elastic modulus is appropriately modified.

In a second study an improved formulation was presented by means of which the crack length, crack tip velocity, bending moment, and axial force at the fracturing section were determined as functions of time after crack initiation. It was found that the effect of the axial force becomes significant after the crack travels about one third of the beam thickness, and better agreement with experimental data is achieved. The results also apply for plane strain fracture of a plate in pure bending provided that the value of the elastic modulus is appropriately modified.

The analytical work was supplemented by numerous experimental investigations. In a first set of experiments, a study was performed to measure crack growth and stress waves generated during fracture of polymethylmethacrylate (PMMA) beams of rectangular cross-section subjected to pure bending. Crack tip motion was determined directly using crack gages. Both bending and longitudinal waves were also measured using strain gages. The nature of crack propagation and the features of the generated stress waves were compared with previous experimental results reported for glass beams. A comparison with the theoretical fracture model discussed above was also made.

In a second set of experiments, different shapes of rectangular beams fabricated from Homolite-100 and PMMA were subjected to pure bending. A crack initiated as a result of the opening of an induced notch. Crack tip motion was determined using crack gages and strain measurements were obtained in close vicinity of the crack with crack-response strain gages. Strain distributions across a cross-section of the beam were obtained as a function of time near the fracture plane. From this study it was found that:

1. The reflected tensile stress pulse from the free ends of the beam is decisive in the last stage of the crack growth.

2. Tensile strains were obtained in close vicinity of the propagating crack tip.

3. An increase in the magnitude of the compressive strain ahead of the propagating crack is decisive in crack branching.

4. The size and shape of the initial notch has a strong influence on the propagating stress wave and on crack branching. The geometry of the height of the beam does not significantly influence the crack branching.

5. During crack branching, the crack takes a turn until it alligns itself parallel to the compressive face of the beam and continues to grow at a speed considerably smaller than the speed prior to branching.

6. The last stage of crack growth can be delayed by using longer beams so that the arrival of the reflected tension pulse at the fracture plane can be delayed.

7. The generally used assumption that the stress distribution is linear through the height of the beam at several beam heights away could lead to inaccuracies in the analysis.

8. Comparisons between measured and calculated dynamic strains near and far away from the crack tip indicate that the dynamic finite element model in this paper is a good representation of the four point bending test under the conditions considered here.

A report summarizing this work is in the final stages of preparation.

The analytical and experimental work was supplemented by numerical investigations. The dynamic finite element program HONDO was modified to determine the stress distribution in a fractured beam. The elements were prestressed to represent the static state of a beam in pure bending. The cracking was modeled by progressively releasing the constraints on the nodes along the advancing crack at a velocity matching the measured crack velocity in the beam. A subroutine was written to solve the differential equation of a beam in the region sufficiently distant from the fracture section. A special element was developed to make the transition from plate to beam elements. This shortened the computing time required in following the loading impulse and the emitted stress waves as they traveled along the beam. From the calculations, large tensile stresses build up initially in front of the cracked tip. As the crack entered the initially-compressed section, these tensile stresses diminished. These results compared well with the experimental results.

A report summarizing this work is in the final stages of preparation.

Further, a separate study was devoted to contrasting some features of the finite difference techniques with finite element methods. When finite difference techniques are used to solve linear elastodynamic problems it is desirable to obtain second order accuracy. Such accuracy is readily obtained from simple central differencing formulae for the field equations,but some care is required in differencing the boundary conditions. A trivial problem of a plane strain sheet subjected to a step function of pressure on the end is solved both by a finite difference scheme defective with regard to boundary conditions and a reliable finite element method, both using explicit integration in time. The results are compared and some comments concerning the accuracy of both finite element and finite difference solutions of linear elastodynamic problems are made.

3. RESEARCH PERSONNEL

The following persons, in addition to the principal investigator, contributed to the project: Dr. Hojjat Adeli, Mr. Suresh Chandra, Dr. Kim Dao, Prof. L.B. Freund, Prof. R.M. McMeeking and Prof. Jackson C.S. Yang.

4. REPORTS AND PUBLICATIONS

L.B. Freund and G. Herrmann, "Dynamic Fracture of a Beam or Plate in Plane Bending", Journal of Applied Mechanics 43, 1976, pp 112-116.

H. Adeli, G. Herrmann and L.B. Freund, "Effect of Axial Force on Dynamic Fracture of a Beam or Plate in Pure Bending", Journal of Applied Mechanics 44, 1977, pp. 647-651.

Kim Dao and George Herrmann, "An Experimental Study of Crack Propagation in Beams During Fracture in Bending", published in the Proceedings of an International Conference on Fracture Mechanics and Technology held in Hong Kong, 1977, Vol. II, pp. 1265-79. Ed: G.C. Sih and C.L. Chow.

Robert M. McMeeking, "On Finite Difference Solutions to Some Linear Elastodynamic Problems" (submitted for publication).

Two reports are in the final stages of preparation as described in Section 2.